NDCEE

National Defense Center for Energy and Environment

# Development of Cadmium and Hexavalent Chromium Free Electrical Connectors: Test Results


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**DoD Executive Agent**

Office of the Assistant Secretary of the Army (Installations and Environment)

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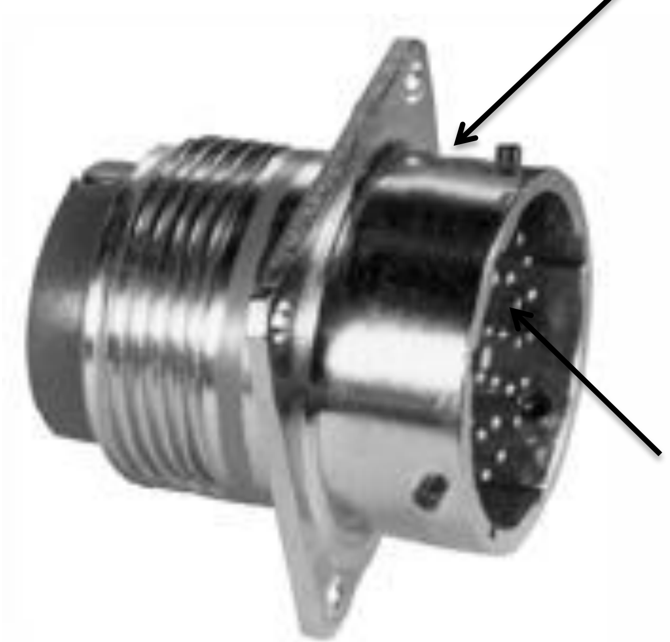
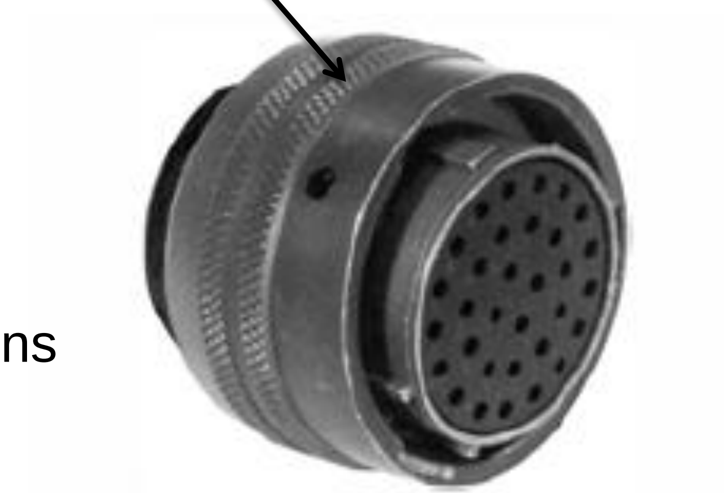
# Presentation Outline

- Background
- Overview
- Test Plan
- Test Results – Phase I
- Test Results – Phase II
- Conclusions
- Summary

# Background

- Focus on shell coatings of military grade electrical connectors


- Receptacle (wall mounting)
- Plug (straight)

# Background (continued)

- Current and emerging regulations require consideration of alternative coating system
  - United States (U.S)
    - Executive Order (EO) 13423, *Strengthening Federal Environmental, Energy, and Transportation Management*
      - Requires Government agencies to reduce quantity of toxic and hazardous chemicals and materials acquired, used, or disposed
    - Cadmium regulated as Hazardous Substance, Hazardous Air Pollutant, Hazardous Waste, Toxic Chemical, and Priority Pollutant (Clean Water Act)
    - Restrictions from
      - Occupational Safety and Health Administration
      - Environmental Protection Agency
  - European Union
    - U.S. military systems exempt BUT could govern part availability in near future
    - Restriction of Hazardous Substances Directive
    - Waste Electrical and Electronic Equipment

# Overview

- Purpose
  - Selection and testing of alternative coatings for electrical connectors used in U.S. Army ground systems
- Goals
  - Compliance with EO 13423
  - Compliance with other current and emerging regulations
  - Reduction of total life cycle costs of connector shell coating systems

# Test Plan

- Substrates, coatings, post-treatments
  - Candidate connector: MIL-DTL-38999 Series III Class W
    - Also test panels as available and needed
  - One substrate: 6061 aluminum
  - Control: cadmium with hexavalent chromium
  - Five cadmium alternatives
    - Electroplated aluminum (AlumiPlate®)
    - Electroplated zinc-nickel (ZnNi)
    - Electroplated tin-zinc (SnZn)
    - Composite electroless nickel (EN) - two types: Durmalon and Polymer Infused Nickel (PIN)
  - Two hexavalent chromium alternative post treatments
    - Trivalent chromium (TCP)
    - Non-chromate post-treatment (NCP)

# Test Plan (continued)

- Phase I (testing as specified under MIL-DTL-38999)
  - Corrosion, Salt Spray
  - Electromagnetic Compatibility/Electromagnetic Interference Effectiveness
  - Fluid Resistance
  - High Temperature Resistance
  - Mating and Unmating Forces
  - Shell-to-Shell Conductivity

# Test Plan (continued)

- Phase II (testing not specified under MIL-DTL-38999 but important to Army)
  - Corrosion, Cyclic
  - Corrosion, Scribed with Primer and Topcoat
  - Corrosion, Sulfur Dioxide
  - Durability in Humidity
  - Galvanic Corrosion Resistance
  - Lubricity (*NOTE: same as Mating and Unmating*)
  - Wear/Handling

# Test Results – Phase I

- Coating Thickness

| Panel Coating System | Vendor-Specified Coating Thickness Range (mils) | Average Determined Thickness (mils) |
|---|---|---|
| Cadmium / hex Cr | 0.8 to 1.5 | 0.34 |
| AlumiPlate / TCP | 0.6 to 1.0 | 0.03 |
| ZnNi / TCP | 0.8 to 1.5 | 0.93 |
| ZnNi / NCP | 0.7 to 1.2 | 0.89 |
| SnZn / TCP | 0.2 minimum | 0.33 |
| SnZn / NCP | 0.2 minimum | 0.42 |
| Durmalon | *(none provided)* | 1.55 |
| PIN | 0.8 to 1.5 | 1.38 |

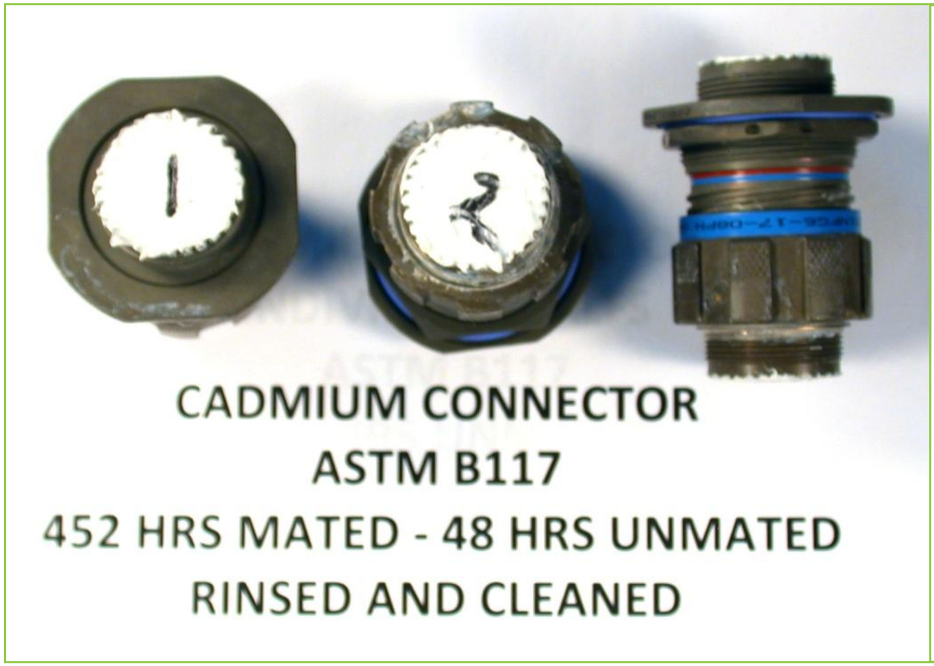
# Test Results – Phase I (continued)

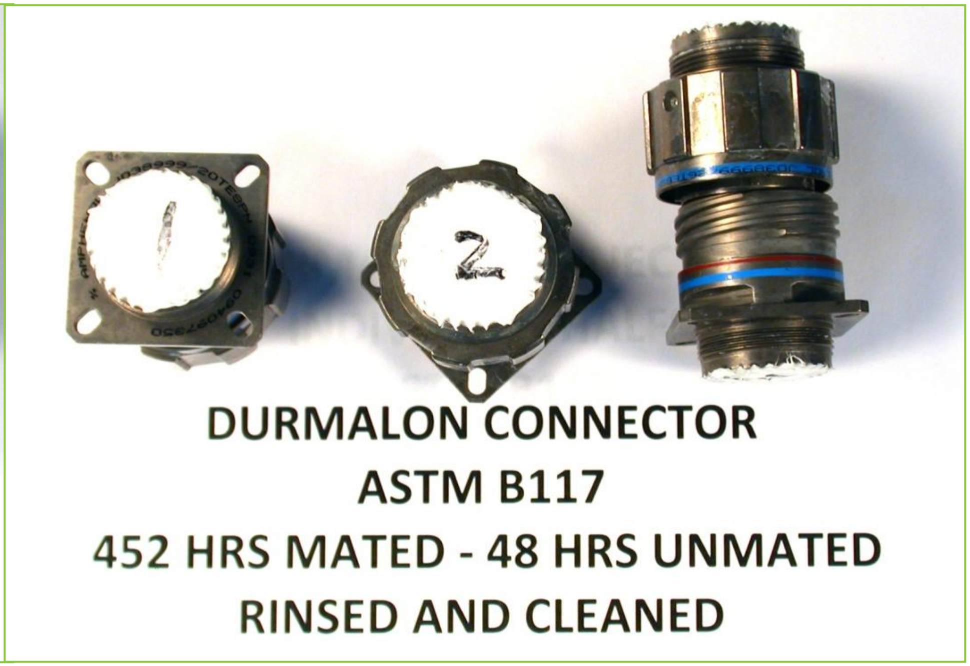
- Coating Thickness (continued)
  - Cadmium met MIL-DTL-38999 requirements
  - AlumiPlate was very low
    - Readings may not be accurate due to method used
  - Remaining candidates had acceptable coating thicknesses

# Test Results – Phase I (continued)

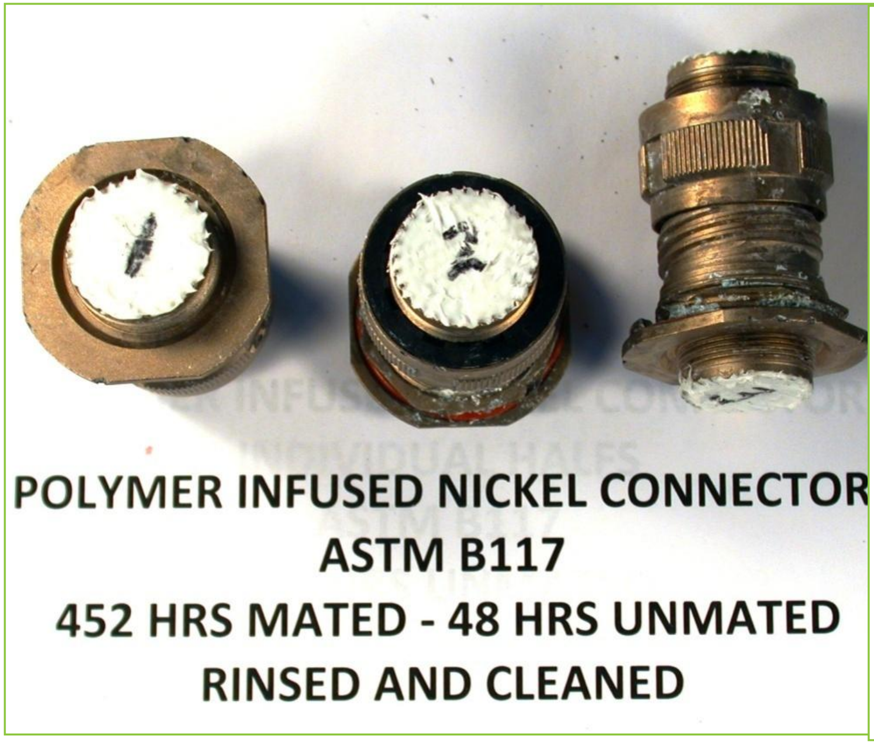
- Corrosion, Salt Spray
  - Cadmium performed well on all specimens, met MIL-DTL-38999 requirements
  - AlumiPlate and two composite nickel candidates performed well on coated panels, similar to cadmium
  - AlumiPlate did not perform well on unmated connectors
  - Neither PIN nor AlumiPlate passed mating/unmating
  - Both versions of SnZn (TCP and NCP) failed on panels
  - Both versions of ZnNi (TCP and NCP) failed all three tests

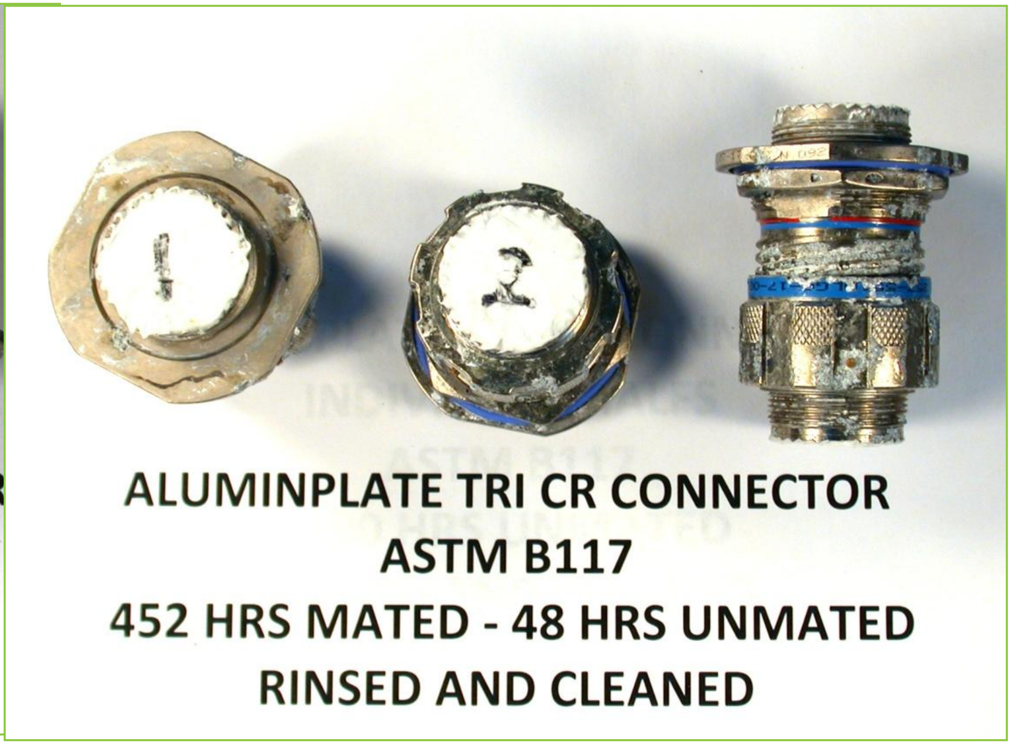
# Test Results – Phase I (continued)



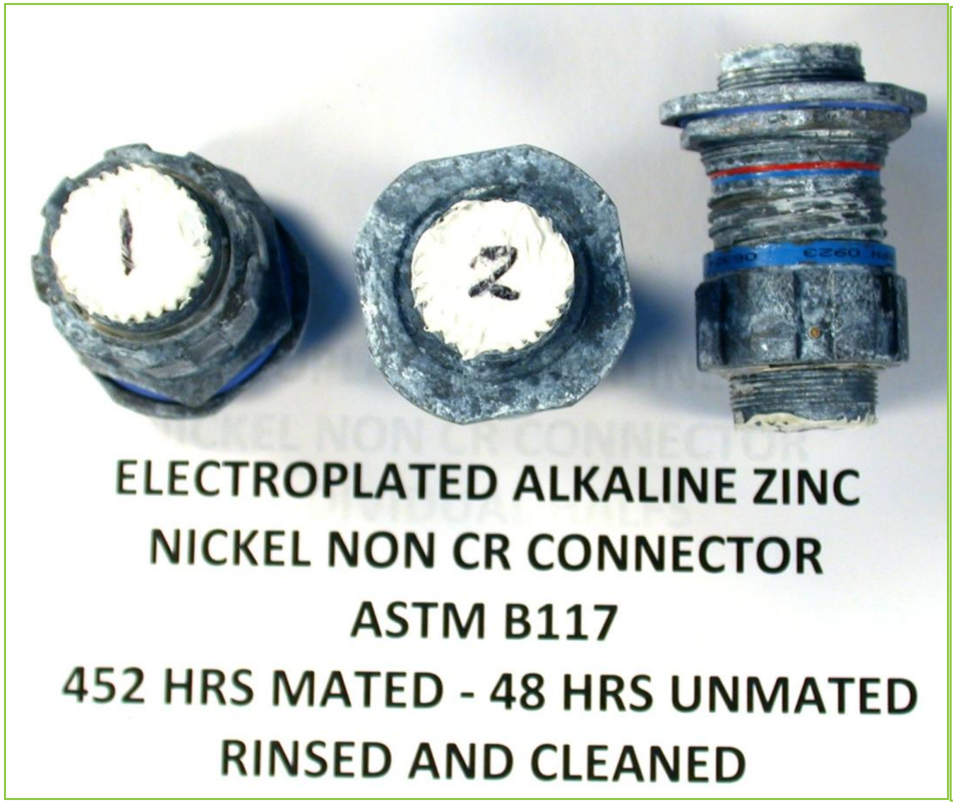



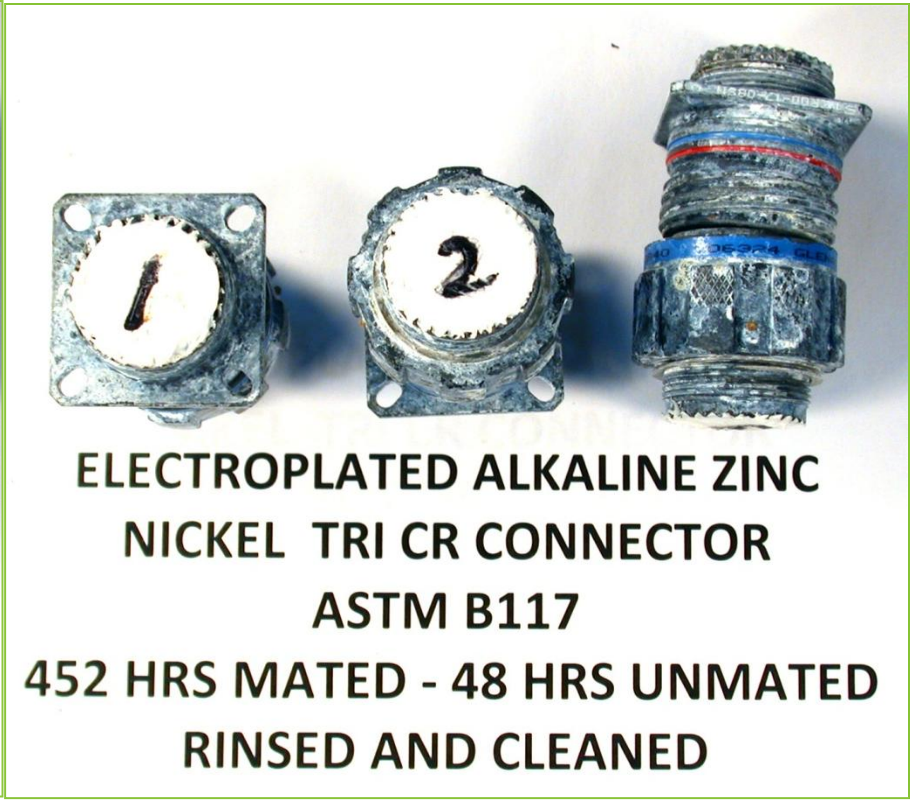
# Test Results – Phase I (continued)



# Test Results – Phase I (continued)



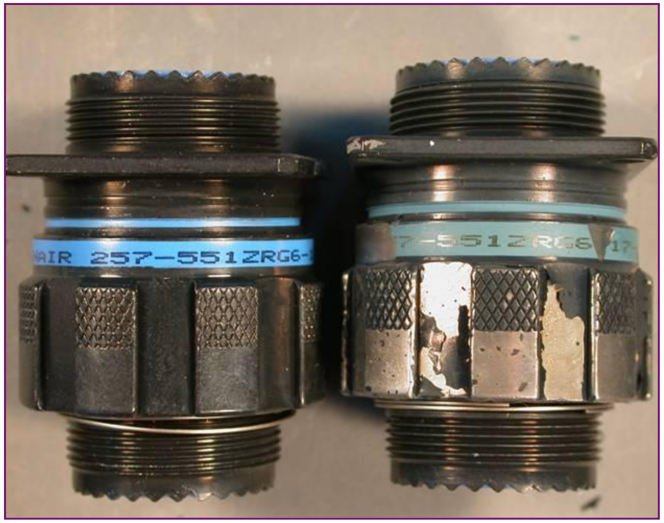
# Test Results – Phase I (continued)

TIN ZINC NON CHROME PANEL
ASTM B117 - 500 HOURS
RINSED AND CLEANED

TIN ZINC TCP PANEL
ASTM B117 - 500 HOURS
RINSED AND CLEANED

# Test Results – Phase I (continued)

- Electromagnetic Compatibility/Electromagnetic Interference Effectiveness
  - Not conducted under this effort
- Fluid Resistance
  - All specimens passed
- High Temperature Resistance
  - All specimens passed except ZnNi with TCP
    - ➢ Shell-to-shell readings varied widely before and after exposure
    - ➢ Coating flaked off after high temperature exposure



# Test Results – Phase I (continued)

- Mating and Unmating
  - All specimens met MIL-DTL-38999 requirements
  - AlumiPlate and ZnNi with TCP demonstrated characteristics closest to cadmium
- Shell-to-Shell Conductivity
  - All specimens passed except ZnNi with TCP
    - Readings varied widely, usually greater than 5 millivolt limit

# Test Results – Phase II

- Corrosion, Cyclic
  - Shell-to-shell conductivity
    - All specimens passed before and after exposure
  - Coupling torque
    - AlumiPlate, ZnNi, and PIN specimens did not pass mating/ unmating requirements on mated connectors

# Test Results – Phase II (continued)

- Corrosion, Scribed with Primer and Topcoat
  - AlumiPlate, ZnNi with TCP, both types of SnZn specimens (TCP and NCP) exhibited performance similar to cadmium
  - Durmalon, PIN, and ZnNi with NCP specimens exhibited failure with total coating delamination
    - Non-aggressive pretreatment employed (acetone wipe) to ensure TCP/ NCP post-treatments would not be degraded
    - Pretreatment likely insufficient to remove tenacious oxide that tends to form on surface of nickel coatings

# Test Results – Phase II (continued)

- Corrosion, Sulfur Dioxide
  - Appearance - cadmium was best performer, followed by ZnNi with TCP
  - Shell-to-shell – all specimens passed
  - Note: fluid gets into connector, increases conductivity
- Durability in Humidity
  - All specimens passed

# Test Results – Phase II (continued)

- Galvanic Corrosion Resistance
  - Test methodology was revised due to material availability - candidate receptacles were mated to a cadmium plug
  - All specimens passed shell-to-shell conductivity
  - All specimens exhibited very minimal corrosion after 168 hours of exposure, except ZnNi with NCP
- Wear/ Handling
  - All candidates passed except two SnZn coatings (TCP and NCP) which failed (total loss of adhesion)

# Conclusions

- Performance ranked vs. cadmium
- Key findings
  - No candidates demonstrated performance as good as or better than cadmium in all tests
  - AlumiPlate, two composite nickels (Durmalon and PIN), and ZnNi with NCP generated highest ratings
    - Dry film lubricant required for AlumiPlate to meet the torque tension requirements
    - Durmalon and PIN coatings require more aggressive pretreatment for painting applications
- Note: One of the composite nickels (Durmalon) approved for 38999 in March 2010

# Conclusions (continued)

- Key findings (continued)
  - ZnNi with TCP demonstrated unusually poor and inconsistent performance, particularly with respect to coating adhesion and shell-to-shell characteristics
  - Both SnZn (TCP and NCP) demonstrated unusually poor and inconsistent performance, failed nearly all tests
- Evaluation of alternative coatings should include testing that correlates to field conditions
- Note:  Team is confirming that none of the alternative coatings received supplemental post-treatments

# Summary

- Current and future environmental regulations will restrict the use of cadmium and hexavalent chromium on electrical connector shells
- To meet this need, this effort has
  - Identified the most commonly used electrical connector design in the inventory (based on data sets provided)
  - Identified five promising candidates to replace cadmium
  - Identified two promising candidates to replace hexavalent chromium
  - Developed a test plan to assess candidate performance for this application
  - Conducted testing to identify best candidates

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